LEVEL

# USER'S MANUAL
# FOR THE
# BUOY-CABLE-BODY COMPUTER PROGRAM
# CABUOY

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CABUOY is a Fortran IV program which solves for the two-dimensional dynamic motions of an ocean deployed cable system in the time domain. The present report, intended as a user's guide for the NAVAIRDEVCEN modified version of CABUOY, describes the various oceanographic systems which can be modeled, explains in detail the input data and procedures required, and defines the output data. An example is presented to demonstrate the use of the program.

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## BACKGROUND

The motions of a cable suspended system deployed in an ocean environment has long been of interest to the oceanographic community. Programs which solve for the steady state cable configuration for systems deployed in a variable current profile have been in use for some time (reference 1,2). Several programs which generate the relative motions of suspended bodies as a result of a random surface forcing function are also in existence. In general, however, these programs model only one specific component of the deployed system, and approximate the remainder of the system. A program which could generate the dynamic motion of an arbitrary cable body system was required.

## INTRODUCTION

CABUOY is a Fortran IV program developed for the Naval Air Development Center by the David Taylor Naval Ship Research and Development Center. The program solves for the two-dimensional dynamic motions of a cable suspended system deployed in an ocean environment (reference 3). Intended as an engineering tool, the program can model any combination of cable segments and attached bodies configured as either a towed, moored, or free drifting system. The positions of all bodies and the resultant cable tensions are calculated as functions of time. This time domain approach, though more costly in terms of execution time than the more common frequency domain method, was chosen because it allows for the solution of transient motions which may induce high tension loads in the cable.

The program employs a finite element analysis to model the cable-body system. The resultant differential equations are integrated using a Kutta-Merson routine which automatically reduces the integration time step until specified error criteria are met. This report will not deal further with the mathematics involved as these are completely described in reference (3). Rather, it will discuss the program input parameters and how they are manipulated to describe various systems, as well as the information available in the output data listing.

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## DISCUSSION

### SYSTEM MODEL

CABUOY solves for the dynamic motions of moored, drifting or towed systems consisting of a surface float and any combination of cable segments and suspended bodies as illustrated in figure 1. Free drifting and towed cases are modeled in the program as moored systems where the bottom cable segment is defined to be massless and highly elastic. The towed system is further considered as a free floating system where the top of the cable is restricted from moving horizontally. The system is then "towed" by inputing a coplanar current velocity of magnitude equal to the tow velocity. The tensions measured in the fictitious cable segment of the drifting system model are generally less than 1 percent of the total system weight and have negligible effects on the dynamic solution.

CABUOY allows the user to arbitrarily define the system's initial position and velocity from which the dynamic data is calculated. Thus, it is possible to compute the time required for a system to reach an equilibrium condition from some initial configuration. Alternatively, the initial conditions can be automatically set to the steady-state values calculated by CABUOY. This minimizes system transients and is useful for generating long term dynamic data. Such versatility greatly increases the usefulness of the program.

### A. Surface Float

Two classes of surface floats can be modeled by CABUOY: spar buoys, defined as buoys with large draft to diameter ratios, and spheroidal buoys whose limiting cases range from a thin disc to a spar. These two classes cover the spectrum of most commonly used surface floats.

During the dynamic calculation phase, CABUOY generates the coefficients for pitch, heave, and surge, and then calculates the response of the float to the surface wave forcing function. Due to the large amounts of computer time normally involved in these calculations, several alternative approximations have been included which reduce execution time at the expense of accuracy. When using these approximations, the surface float drag areas and added mass remain constant at the steady-state values or are calculated only at the end of each print interval. These approximations, though not accurate, are useful when evaluating the effects of subsurface assembly changes on system performance where many runs may be necessary.

The user also has the option of coupling the surface float directly to the ocean surface, eliminating the interaction between waves and float. This mode is useful in representing a system deployed off of a ship when the ship motion is known. The typical laboratory arrangement where an oscillating arm drives the top of the cable and the response of the lower unit is measured can also be simulated in this manner.

### B. Cable

In CABUOY, the system suspension is divided into a number of rigid extensible segments whose end points are defined by the bodies suspended on the cable. To minimize the errors induced by the assumption of a rigid cable, long continuous cable length can be divided up into several segments. This is especially useful at the top of the system where the cable catenary is greatest.

<del>4</del>

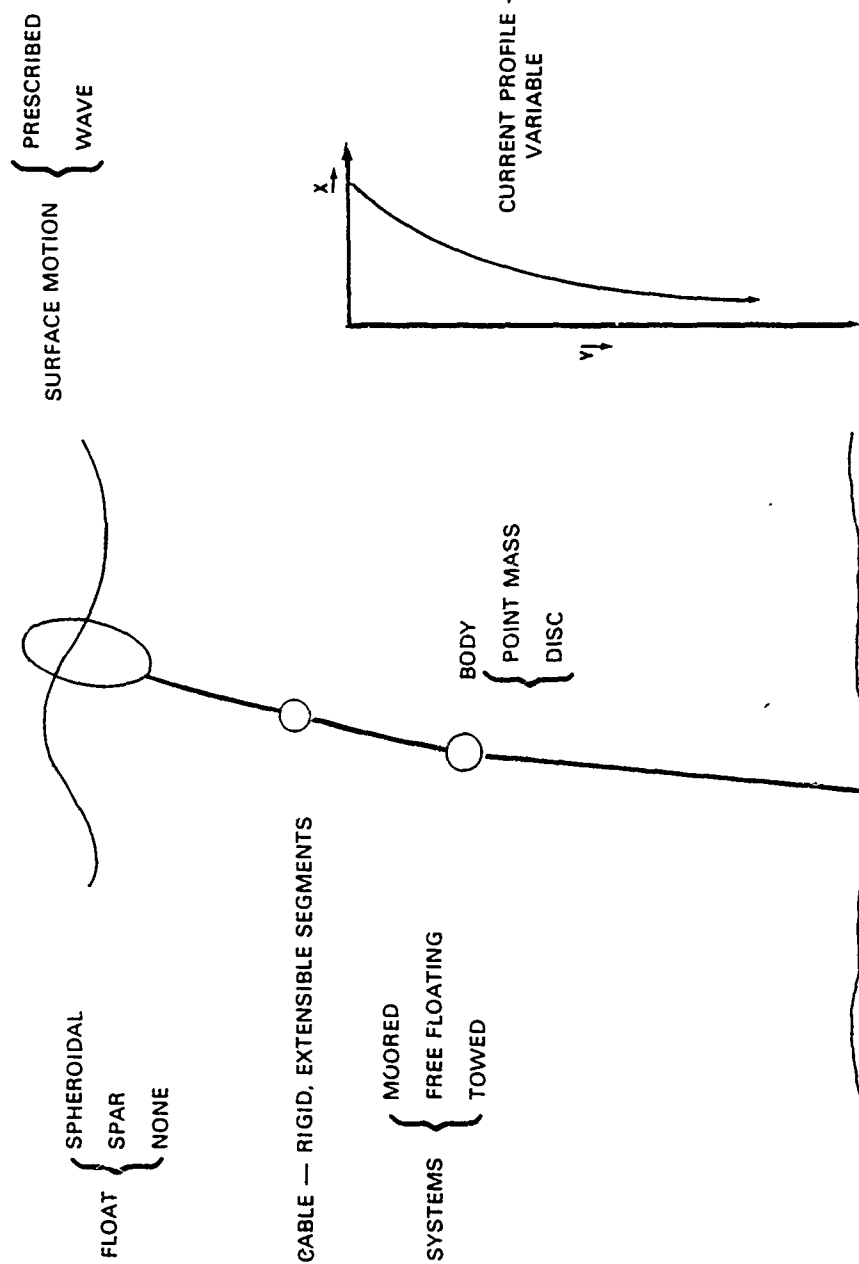Figure 1 - CABUOY (Model Definition)

CABUOY
MODEL DEFINITION

SURFACE MOTION { PRESCRIBED WAVE

CURRENT PROFILE - VARIABLE

FLOAT { SPHEROIDAL SPAR NONE

CABLE — RIGID, EXTENSIBLE SEGMENTS

SYSTEMS { MOORED FREE FLOATING TOWED

BODY { POINT MASS DISC

The stress-strain relationship for each cable segment is defined by:

$$T = C1^* \epsilon^{C2} + CINT^* \dot{\epsilon} + TREF$$

where

$T$ = cable tension

$C_1, C_2$, are constants

$\epsilon$ = strain

$CINT$ = Internal Damping Coefficient

$\dot{\epsilon}$ = time rate of change of strain

$TREF$ = constant

This equation allows CABUOY to model nonlinear cables, such as bungee cords, as well as linear materials such as steel and Kevlar, through the appropriate choice of coefficients.

## C. Suspended Bodies

All suspended bodies are considered to be point masses of known drag area and virtual mass, with all forces acting at the center of gravity of the body Because of their wide use as vertical motion isolation in sonobuoy systems, a special routine has been included for flat discs which calculates the virtual mass as a function of the oscillation amplitude. For cases where several bodies are connected by short cable segments, such as in an instrumented line array, it is advantageous to input the bodies as a single element with a drag area equal to that of the entire array. This minimizes the number of cable segments and thus the execution time without significantly increasing the computational error.

## ENVIRONMENT

The ocean environment utilized in CABUOY consists of a user-defined sea surface which decays exponentially with depth in conjunction with a variable current velocity profile. The ocean surface is generated by the summation of N sine waves, the amplitudes, frequencies, and phases of which may be defined by the user or by an internal wave generator. The current profile is input as a table of velocity versus depth. For the moored system, the depth of the last current velocity is defined to be the ocean bottom. For a free floating system, the current velocity at all depths greater than the maximum depth specified is equal to the last current velocity input.

## DATA INPUT

CABUOY input data is arranged as illustrated in figure 2. Program variables are defined in appendix A, along with a data format guide. In general, data input is a straight forward process. However, because of the various systems CABUOY is designed to evaluate, several variables have multiple definitions, depending on which system is being analyzed. This section will review just those variables.
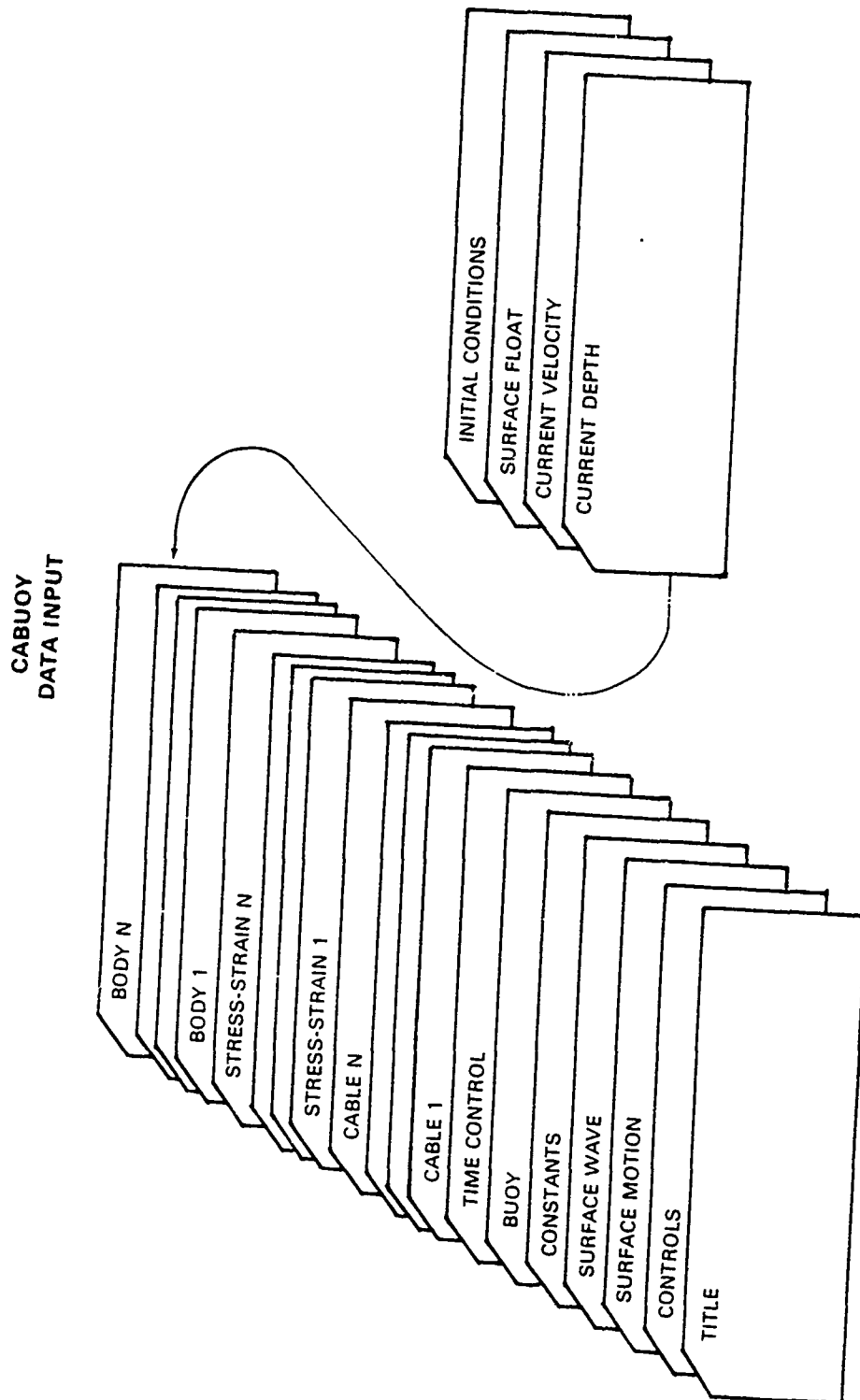
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Figure 2 - CABUOY (Data Input)

## A. FSM

The motion at the top of the cable is dependent on the variable FSM (figure 3). When FSM is less than 1000, the motion is defined by a summation of sine waves with a frequency, amplitude, and phase determined by the variables AXSM, AYSM, FSM, and FIDSM. This motion acts directly at the top of the cable system and eliminates the surface float from the calculations. For $1000 \leq FSM < 2000$, the motion at the top of the cable is set equal to the surface waves defined by FSW, ASW, and FIDSW. The surface float is again eliminated from the calculations.

In those cases where $2000 \leq FSM < 2900$, the program considers the surface float to be a spar buoy, and calculates the response of the cable buoy system to the surface wave forcing function. The float is defined by considering AXSM (k) to be the cross sectional area of the buoy at a vertical distance AYSM (k) from the origin of the local buoy coordinate system. All inertia and coupling coefficients are calculated by the program. The origin of the float coordinate system can be anywhere the user defines, and AYSM should be negative or positive as required to define areas above and below the origin.

Where $2900 \leq FSM < 3000$, the buoy is considered to be an arbitrary shape defined in the same manner as a spar buoy. However, all inertia and coupling coefficients are defined by the user. For $3000 < FMS < 4000$, the program considers the float to be a spheroid. AXSM (1) and AYSM (1) are considered to be the horizontal and vertical semi-axes respectfully. All inertia and coupling coefficients are again calculated by the program. The origin is considered to be at the geometric center of the float.

Additional data required to define the surface float as well as any subsurface package are input on separate cards. All required variables are defined in appendix A. Figure 4 illustrates the various forces and their geometric relationship to the float $C_g$ It should be noted that the input variable TIY represents the force at the top of the cable. As this force is in a vertical up direction, the value enter for TIY is the negative of the actual value.

## B. ASW

The surface wave forcing function is defined by ASW (figure 5). When $ASW < 1000$, the user inputs the amplitude, frequency, and phase of up to 20 sinusodial wave components which are then summed together to generate the surface wave. For $1000 \leq ASW < 2000$, the program generates a random sea surface with wave components calculated from the Pierson-Moskowitz energy spectrum for a well developed sea. ASW (1) - 1000 is equal to the significant wave height, and FRSW (1) and FRSW (2) are the lower and upper frequency limits for the spectrum. All components are phase shifted relative to each other by 360/NSW degrees.

For the case where $2003 \leq ASW \leq 2008$, a standard random sea surface is generated using wave components defined by the program reference (4). ASW - 2000 is equal to the desired sea state.

## C. Output Time Increments

The variables DT1, DT2, TINV1, and TOTT are used to control the output of the dynamic solution (figure 6). TINV1 defines an initial interval during which data is printed every DT1 seconds. This interval could be used to give limited information during a period where transient system motions are decaying For all times after TINV1 until TOTT, data is printed out every DT2 seconds. This would be where fine resolution is required to analyze long term motions. The time increments could be changed if the user was more interested in the initial system response, and how much time was required to reach steady state

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CABUOY
SURFACE MOTION

| FSM < 1000 | 1000< FSM < 2000 | 2000 < FSM < 3000 | 3000 < FSM |
|---|---|---|---|
| SURFACE MOTION | SURFACE MOTION | SPAR BUOY | SPHEROID |
| EQUALS | EQUALS | | |
| SUMMATION | SURFACE WAVE | | |
| OF | | | |
| SINE WAVES | | | |
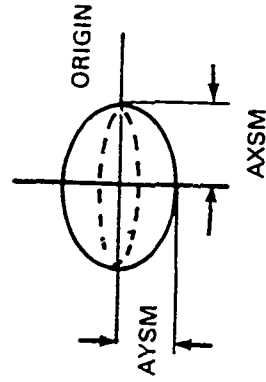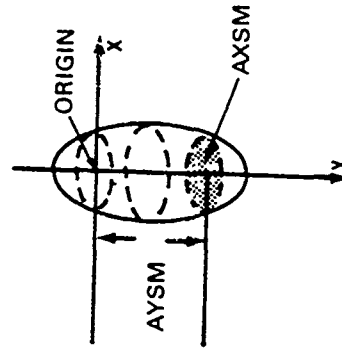


VARIABLES: AXSM   AYSM   FSM   FIDSM

Figure 3 - CABUOY (Surface Motion)

## SURFACE FLOAT GEOMETRY
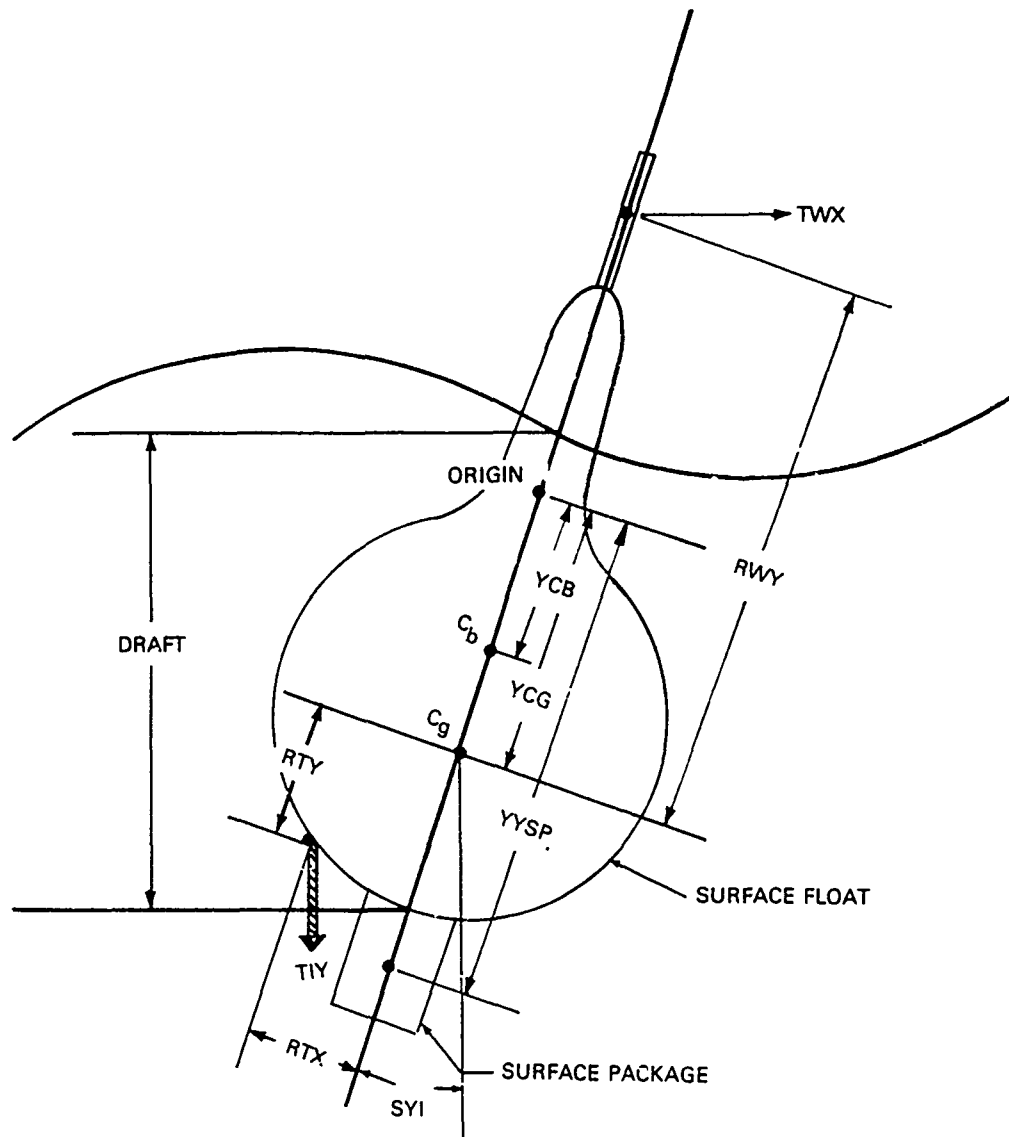


Figure 4 - Surface Flat Geometry

**CABUOY
SURFACE WAVE**
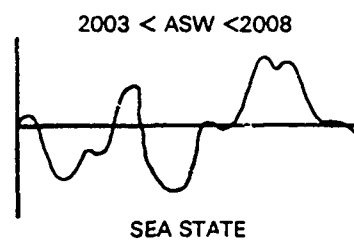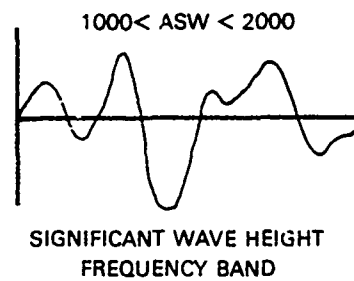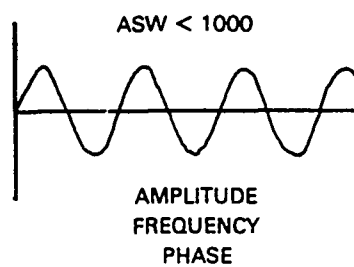
ASW < 1000

**AMPLITUDE
FREQUENCY
PHASE**

1000< ASW < 2000

**SIGNIFICANT WAVE HEIGHT
FREQUENCY BAND**

2003 < ASW <2008

**SEA STATE**

Figure 5 - CABUOY (Surface Wave)

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Figure 6 - CABUOY (Time Control)
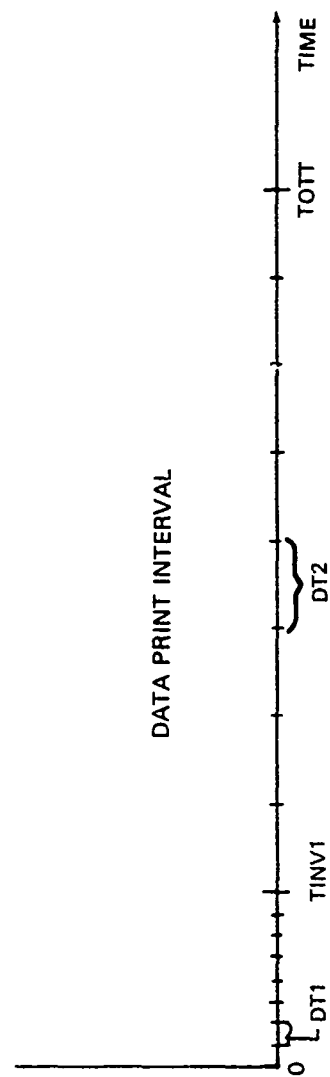
### D. Cable Stress Versus Strain

CABUOY uses the generalized equation:

$$\text{Tension} = \text{TREF} + C1 * \varepsilon^{C2} + \text{CINT} * \dot{\varepsilon}$$

to relate cable stress and strain (figure 7). This equation allows the user to closely model the behavior of many varied cable materials. For a linearly elastic material, $C2 = 1$ and $C1 = AE$, where A is the cable cross sectional area and E is the elastic modulus. For a nonlinear material, the user can select values of C1 and C2 to closely model the material in the immediate area of interest. It should be noted that if TREF is nonzero, the cable length input should be at a tension of TREF. TMIN must also be defined to prevent the cable from being compressed during the dynamic phase.

### E. Bodies

CABUOY considers each body to be a point mass with a fixed drag area. For those special cases where the body is a circular damping disc, a special routine is available which calculates the effective drag and added mass terms as a function of the oscillation amplitude. The user enables this routine by entering the negative of the physical drag area for the variable CDABX if the disc is oriented in the X-Z plane, or the variable CDABY if the disc is in the Y-Z plane. The remaining drag area would be entered normally.

### DATA OUTPUT

Data output is formatted as illustrated in figure 8. First, all input data are listed. The program calculates and outputs the surface float constants required for the dynamic calculations based upon the draft estimate from the input data. Using these values as initial approximations, the program calculates the steady-state configuration of the system. These steady-state calculations use the finite element analysis techniques and iteration routines from the programs FF2E and MR3E, and considers the cables to be flexible extensible segments. The results are more accurate than would be obtainable using the rigid cable segments. The results from each iteration are printed out, and when a solution is reached the constants for the surface buoy are recomputed and output for the actual float draft. The exact surface float tilt is written, as well as the approximate float tilt used in the dynamic calculations. The approximate tilt may vary from the exact tilt as a result of the cable assumptions (rigid extensible segment) made for the dynamic phase.

The program then lists the steady-state configuration of the cable system. This represents the "exact" steady-state system configuration. By fitting the rigid CABUOY cable segments to the exact solution, the program generates a set of initial cable conditions which will be used in the dynamic calculations if required by the user. The program then calculates the cable motions and tensions and outputs these data as a function of time. Data are output for the surface wave (WAVE), surface float center of gravity (BUOY), top of the cable (Node 0), and the bottom of each cable segment (Nodes 1,2,3 etc). No data are output for the bottom of the last cable segment, which is assumed to be fixed in space. While the program computes the dynamic motions, it also stores the percentage of the time that float draft and pitch exceed predefined limits. These percentages are then output at each print interval.

### CABUOY EXAMPLE

To demonstrate the application of CABUOY for the solution of a real world problem, the moored system illustrated in figure 9 was evaluated and the input/output data listed in tables I and II. It is suggested that the example be closely studied and understood before the user attempts a problem of his own.

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CABUOY
STRESS-STRAIN

TENSION = TREF + C1$\epsilon$C2 + CINT $\dot{\epsilon}$

$T = TREF + AE\epsilon$

$T = TREF + C1\epsilon^{C2}$

LINEAR
APPROX.

CURVE FIT

VARIABLES
STRESS STRAIN — C1    C2    CINT    TREF
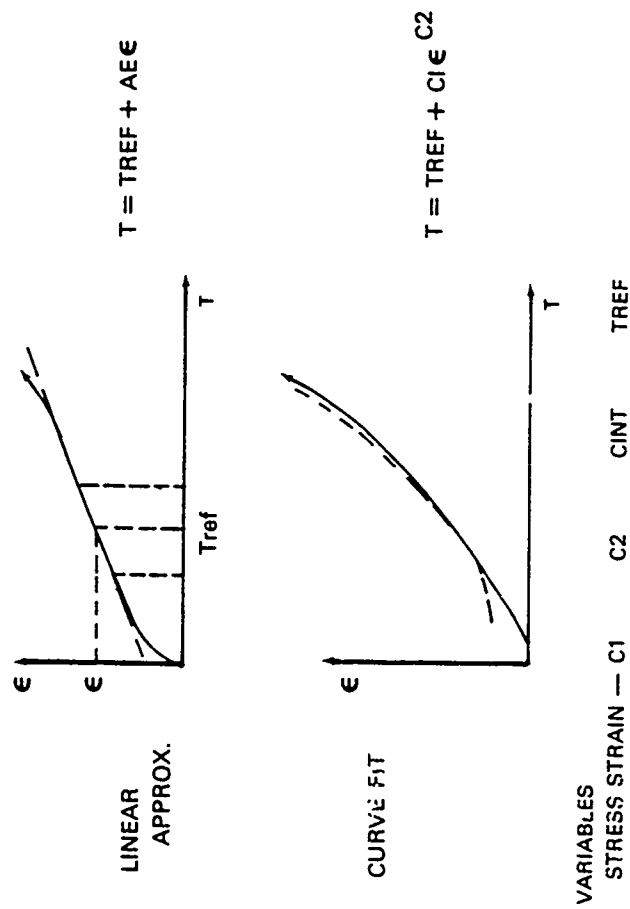
Figure 7 - CABUOY (Stress-Strain)

CABUOY
DATA OUTPUT

I    INPUT PARAMETERS

II   STATIC SOLUTION

     POSITION (X,Y)          TENSION          ANGLE (Φ)

III  DYNAMIC SOLUTION

| | TIME | DT | POSITION | VELOCITY | ACCELERATION | TENSION | ANGLE | STRAIN |
|---|---|---|---|---|---|---|---|---|
| WAVE | | | | | | | | |
| BUOY | | | | | | | | |
| NODE | | | | | | | | |
| NODE | | | | | | | | |

Figure 8 - CABUOY (Data Output)
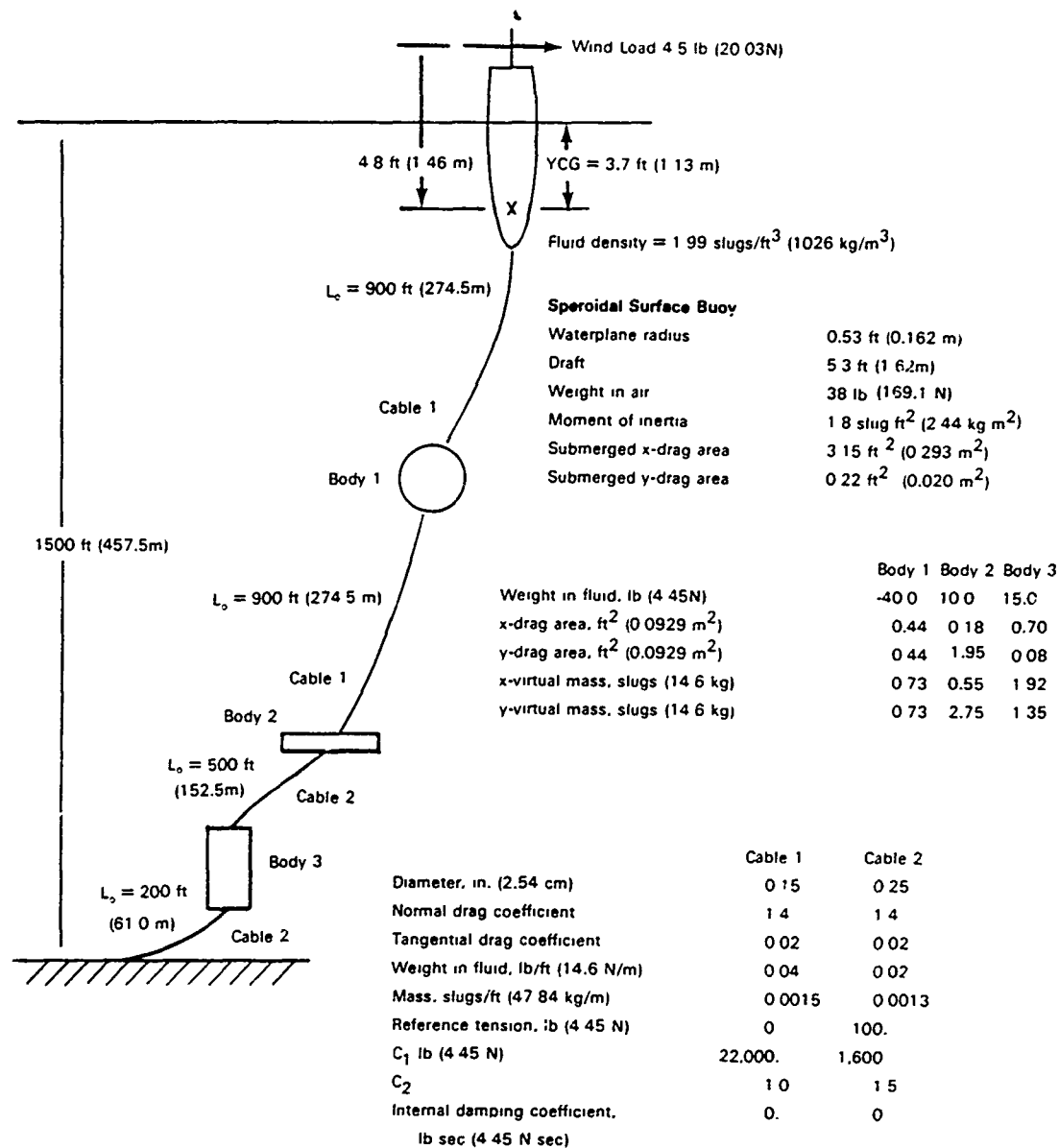
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Figure 9 - Parameters for Moored Buoy-Cable-Body System

## Program Time Requirement

As noted in the original NSRDC report, CABUOY requires a large amount of memory and may take several minutes of CPU time to generate a solution. Generally, the number of surface waves or motions (NSW or NSM) and cable segments (NCAB), the stiffness of the cable segments (AE), the degree of surface float approximations (IBUOY), and the amount of output data required (TOTT) are the primary factors affecting the execution time. The following techniques will reduce the required computer time.

NSW/NSM - Reducing the number of surface wave components will reduce execution time. Generally, it is possible to evaluate systems response to a simple harmonic motion. Only in selected cases would the user evaluate system response to a random sea surface.

NCAB - Reducing the number of cable segments will directly reduce execution times (NCAB $\geq$ 2). Generally, near surface cable segments should be divided into small lengths, while deep segments can be grouped into one long segment. Often a vertical hydrophone array can be approximated by one cable segment where cable drag area is defined to be equivalent to the array drag, with appreciable reductions in CPU time.

AE - Stiff cable segments (high equivalent spring constants) require longer execution time because of the smaller time increments used during the integrations. If possible, it would be more efficient to input a shorter, more elastic segment which will stretch to the original cable segment length. The effects of this change on the system response will have to be evaluated by the user.

IBUOY - Generally, the more often surface float constants have to be calculated, the more execution time is required. Therefore, unless the accuracy is required, the user can economize by setting IBUOY equal to 0 or 1. Setting IBUOY equal to -10 should be avoided except in cases where surface float motion is limited.

TOTT - Obviously, the more output data required, the longer the program will run. Execution is not affected by increasing DT1 or DT2, as the integration time step is determined by the computer, and this determines execution time. The only charges which change with DT1 and DT2 are those associated with line printers.

## TABLE I
## INPUT PARAMETERS

| Card | Col | FMT | Variable | Data | | | | |
|------|-----|-----|----------|------|------|------|------|------|
| 1 | 1-3 | I3 | NCASES | 001 | | | | |
| 2 | 1-80 | 20A4 | TITLE | CABUOY-CASE 2 of NSRDC Report | | | | |
| 3 | 1-3 | I3 | NSM | 001 | | | | |
| | 4-6 | I3 | NSW | 001 | | | | |
| | 7-9 | I3 | NCAB | 005 | | | | |
| | 10-12 | I3 | NCUR | 004 | | | | |
| | 13-15 | I3 | ITER | 002 | | | | |
| | 16-18 | I3 | MTRC | 000 | | | | |
| | 19-21 | I3 | IBUOY | -01 | | | | |
| | 22-24 | I3 | ISPAR | 0 | | | | |
| 4 | 1-10 | F10.4 | AXSM (I) | .530 | | | | |
| | 11-20 | F10.4 | AYSM (I) | 5.3 | | | | |
| | 21-30 | F10.4 | FSM (I) | 3500. | | | | |
| | 31-40 | F10.4 | FIDSM (I) | 1.0 | | | | |
| 5 | 1-10 | F10.4 | ASW (J) | 7.5 | | | | |
| | 11-20 | F10.4 | FRSW (J) | .10 | | | | |
| | 21-30 | F10.4 | FIDSW (J) | 0.0 | | | | |
| 6 | 1-10 | F10.4 | RHO | 1.99 | | | | |
| | 11-20 | F10.4 | AMC | 1.0 | | | | |
| | 21-30 | F10.4 | AFAC | 1.0 | | | | |
| | 31-40 | F10.4 | TBH | .0 | | | | |
| | 41-50 | F10.4 | TBYMX | 999999. | | | | |
| 7 | 1-10 | F10.4 | SUBM | 0.0 | | | | |
| | 11-20 | F10.4 | TWX | 4.5 | | | | |
| | 21-30 | F10.4 | TIY | -100. | | | | |
| | 31-40 | F10.4 | TMIN | 0. | | | | |
| 8 | 1-10 | F10.4 | CDASPX | 0.0 | | | | |
| | 11-20 | F10.4 | CDASBX | 6.3 | | | | |
| | 21-30 | F10.4 | VSP | 0.0 | | | | |
| | 31-40 | F10.4 | SPXK | 0.0 | | | | |
| | 41-50 | F10.4 | SPYK | 0.0 | | | | |
| | 51-60 | F10.4 | YYSP | 0.0 | | | | |
| 9 | 1-10 | F10.4 | TINVI | 10.0 | | | | |
| | 11-20 | F10.4 | DTI | 0.1 | | | | |
| | 21-30 | F10.4 | TOTT | 50.0 | | | | |
| | 31-40 | F10.4 | DT2 | 0.5 | | | | |
| 10 | 1-0 | F10.2 | FLC (K) | 200. | 700 | 900. | 500. | 200. |
| | 11-20 | F10.4 | DCI (K) | .15 | .15 | .15 | .25 | .25 |
| | 21-30 | F10.4 | CDN (K) | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 |
| | 31-40 | F10.4 | CDT (K) | .02 | .02 | .02 | .02 | .02 |
| | 41-50 | F10.4 | WC (K) | .04 | .04 | .04 | .02 | .02 |
| | 51-60 | F10.6 | CM (K) | .0015 | .0015 | .0015 | .0013 | .0013 |
| 11 | 1-10 | F10.0 | C1 (K) | 22000. | 22000. | 22000. | 1600. | 1600. |
| | 11-20 | F10.4 | C2 (K) | 1.0 | 1.0 | 1.0 | 1.5 | 1.5 |
| | 21-30 | F10.4 | CINT (K) | 0. | 0. | 0. | 0. | 0. |
| | 31-40 | F10.2 | TREF (K) | 0. | 0. | 0. | 100. | 100. |
| | 41-50 | F10.2 | TENI (K) | 0. | 0. | 0. | 0. | 0. |
| | 51-60 | F10.4 | PHID (K) | 9999. | 0. | 0. | 0. | 0. |
| | 61-70 | F10.4 | XPI (K) | 0. | 0. | 0. | 0. | 0. |
| | 71-80 | F10.4 | YPI (K) | 0. | 0. | 0. | 0. | 0. |

## TABLE I
## INPUT PARAMETERS (Cont'd)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 12 | 1-10 | F10.4 | WBD (K) | 0.0 | -40.0 | 10.0 | 15.0 | 0.0 |
| | 11-20 | F10.4 | CDABX (K) | 0. | .44 | .18 | .7 | 0.0 |
| | 21-30 | F10.4 | CDABY (K) | 0. | .44 | 1.95 | .08 | 0. |
| | 31-40 | F10.4 | XMBV (K) | 0. | .73 | .55 | 1.92 | 0. |
| | 41-50 | F10.4 | YMBV (K) | 0. | .73 | 2.75 | 1.35 | 0. |
| 13 | 1-10,.... | F10.4 | YY(L) | 0. | 500. | 1000. | 1500. | |
| 14 | 1-10,.... | F10.4 | CCK (L) | 2.5 | 1.3 | 0.5 | 0.5 | |
| 15 | 1-10 | F10.4 | CDASY | 0.22 | | | | |
| | 11-20 | F10.4 | WAST | 38.0 | | | | |
| | 21-30 | F10.4 | RWY | -4.8 | | | | |
| | 31-40 | F10.4 | RTX | 0. | | | | |
| | 41-50 | F10.4 | RTY | 1.6 | | | | |
| | 51-60 | F10.4 | YCG | 3.7 | | | | |
| | 61-70 | F10.4 | BINT | 1.8 | | | | |
| 16 | 1-10 | F10.4 | XSI | 7.5 | | | | |
| | 11-20 | F10.4 | ZETI | 0. | | | | |
| | 21-30 | F10.4 | SYDI | 999. | | | | |
| | 31-40 | F10.4 | XPSI | 0. | | | | |
| | 41-50 | F10.4 | ZTPI | 0. | | | | |
| | 51-60 | F10.4 | SYPDI | 0. | | | | |
| | 61-70 | F10.4 | DFTLIM | 5.5 | | | | |
| | 71-80 | F10.4 | SYDLIM | 25. | | | | |

## TABLE II
## OUTPUT LISTING

...... CABUOY        CASE 2 OF NSHUL REPORT

LISTING OF ENVIRONMENTAL AND CABLE-BUOY CHARACTERISTICS

OCEAN CONDITIONS

SURFACE WAVE-    FREQ(CPS) AMPL(FT) PHASE(0)   WL(FT)  WK(1/FT)
                  .100      7.50      .00      512.40    .0123

CURRENT PROFILE   DEPTH(FT)  CURR(KT)
                    .00       2.50
                  500.00      1.30
                 1000.00       .50
                 1500.00       .50

FLUID DENSITY=  1.9900 SL/CUFT

SURFACE MOTION-FNE@(CPS)  X-A(FT)   Y-A(FT)  PHASE(DEG)
                3500.0000  .5300    5.3000    1.0000

GENERAL CABLE CHARACTERISTICS

AM COEFF  AREA FAC  T MIN(LB)
 1.0J00   1.0000      .00

CABLE PROPERTIES
| NUM | LEN(FT) | DIAM(IN) | CDN | CDT | W(LB/F) | M(SL/F) | T REF(LB) | CI(LB) | EXP C2 | CINT(LB) |
|-----|---------|----------|-----|-----|---------|---------|-----------|--------|--------|----------|
| 1 | 200.00 | .1500 | 1.4000 | .0200 | .0400 | .001500 | .00 | 22000. | 1.0000 | .0000 |
| 2 | 700.00 | .1500 | 1.4000 | .0200 | .0400 | .001500 | .00 | 22000. | 1.0000 | .0000 |
| 3 | 900.00 | .1500 | 1.4000 | .0200 | .0400 | .001500 | .00 | 22000. | 1.0000 | .0000 |
| 4 | 500.00 | .2500 | 1.4000 | .0200 | .0200 | .001300 | 100.00 | 1600. | 1.5000 | .0000 |
| 5 | 200.00 | .2500 | 1.4000 | .0200 | .0200 | .001300 | 100.00 | 1600. | 1.5000 | .0000 |

X-LOAD ON BOT WT=   .0000 LB

SURFACE BUOY CHARACTERISTICS

BODY PROPERTIES
| CDAX(F2) | CDAY(F2) | WT(LB) | XVM(SL) | YVM(SL) |
|----------|----------|--------|---------|---------|
| .000 | .000 | .000 | .0000 | .0000 |
| .440 | .440 | -40.000 | .7300 | .7300 |
| .180 | 1.950 | 10.000 | .5500 | 2.7500 |
| .700 | .080 | 15.000 | 1.9200 | 1.3500 |
| .000 | .000 | .000 | .0000 | .0000 |

SUBM(FT)  WIND LD(LB)  CDASPX(FTSQ)  CDASHX(FTSQ)  VSP (FTCU)  SPXK  SPYK  YYSP(FT)  MAX TEN(LB)  BUOY CALC  SPAR NUM
 .0000     4.5000       .0000         6.3000       .0000      .0000  .0000  .0000    999999.0000  -1.0000     .0000

SURFACE BUOY PARAMETERS

CDAY(FTSQ)  WT(LB)   HWY(FT)    RTX(FT)   RTY(FT)   YCG(FT)   IN(SLF)SQ)  XI(FT)   ZETA(FT)   SYI(DEG)  XVI(F/S)  ZTVI(F/S)  SVI(D/S)
 .2200     36.0000  -4.8000     .0000     1.6000    3.7000    1.8000     7.5000    .0000     999.0006   .0000     4.7124     .0000

LIMIT DRAFT= 5.5000 FT    LIMIT PITCH= 25.0000 DEG

CONSTANTS FOR SPHEROIDAL BUOY
DRAFT(FT)  A(FT)   DRAFT/A   VOL(CUFT)  VOL*Y(FT4)    FXM     FKP       FKPS      FYS     FYK      RGSO      CDAFC    CDASX
 .9493     .5288  9.3589    2.8091     -4.2506       .0325   17.4783   -3.4572   .9542             56.2996   .4579    2.8848
YCM-YCG= -1.5131 FT
EXACT SYI= 22.2170 DEG    APPR SYI=  22.2370 DEG

| ITN | VCXX | TIXX | TIYY | TLNH | PMIW | TWXX | THYY | XXBR | YYBB | SYSS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .00000 | 55.60535 | -142.00000 | 123.11841 | 81.23570 | -121.68084 | 18.75940 | -2109.34974 | 1324.59583 | 22.23704 |
| 2 | .00000 | 116.10550 | -3621.00000 | 3552.04979 | 3.84121 | -237.96108 | 3544.07001 | -230.48531 | 3971.25693 | 4.12464 |
| 3 | .00000 | 116.10550 | -1881.50000 | 1814.71153 | 7.69709 | -243.05485 | 1748.36100 | -392.50502 | 3377.61502 | 7.91752 |
| 4 | .00000 | 116.10550 | -1011.75000 | 949.47875 | 14.81405 | -242.76534 | 917.91878 | -663.57114 | 2981.66754 | 11.47479 |
| 5 | .00000 | 116.10550 | -576.87500 | 523.57870 | 26.58192 | -234.28936 | 468.23408 | -1063.89626 | 2639.08861 | 14.79942 |
| 6 | .00000 | 116.44328 | -359.43750 | 320.48101 | 42.11122 | -214.90558 | 237.74707 | -1513.77331 | 2256.49387 | 17.20717 |
| 7 | .00000 | 81.71847 | -250.71875 | 213.81552 | 53.77529 | -172.44601 | 126.35505 | -1725.44663 | 1918.59589 | 20.14764 |
| 8 | .00000 | 68.51510 | -196.35937 | 165.44525 | 64.47248 | -149.29420 | 71.29774 | -1900.09353 | 1727.54483 | 20.34742 |
| 9 | .00000 | 62.05238 | -169.17969 | 143.25567 | 71.87658 | -136.14856 | 44.56181 | -2002.51244 | 1551.04167 | 20.79856 |
| 10 | .00000 | 58.83059 | -155.58984 | 132.88535 | 76.27832 | -129.09273 | 31.52117 | -2055.95279 | 1444.98634 | 21.07494 |
| 11 | .00000 | 60.44152 | -162.38477 | 138.00195 | 74.01313 | -132.66470 | 38.00810 | -2029.15406 | 1499.66807 | 19.96072 |
| 12 | .00000 | 61.24810 | -165.78623 | 140.61201 | 72.92829 | -134.41637 | 41.27925 | -2015.79392 | 1525.77400 | 19.91978 |
| 13 | .00000 | 60.84442 | -164.08350 | 139.30184 | 73.46573 | -133.54166 | 39.64375 | -2022.45809 | 1512.84063 | 20.17966 |
| 14 | .00000 | 60.64317 | -163.23413 | 138.65008 | 73.73762 | -133.10261 | 38.82708 | -2025.79710 | 1506.29413 | 20.19160 |
| 15 | .00000 | 60.54126 | -162.80945 | 138.32534 | 73.67576 | -132.88432 | 38.41609 | -2027.47610 | 1502.98072 | 20.19772 |
| 16 | .00000 | 60.49139 | -162.59711 | 138.16383 | 73.94437 | -132.77456 | 38.21206 | -2028.31533 | 1501.32595 | 20.20048 |
| 17 | .00000 | 60.46754 | -162.49094 | 138.08343 | 73.97883 | -132.72024 | 38.10999 | -2028.73979 | 1500.49205 | 20.20187 |
| 18 | .00000 | 60.45453 | -162.43785 | 138.04269 | 73.99598 | -132.69248 | 38.05904 | -2028.94693 | 1500.08016 | 20.20288 |
| 19 | .00000 | 60.44803 | -162.41131 | 138.02232 | 74.00455 | -132.67859 | 38.03357 | -2029.05049 | 1499.87414 | 20.20322 |
| 20 | .00000 | 60.45020 | -162.42458 | 138.03195 | 74.00016 | -132.68493 | 38.04636 | -2028.99360 | 1499.98251 | 20.20124 |
| 21 | .00000 | 60.45236 | -162.43122 | 138.03732 | 73.99807 | -132.68871 | 38.05271 | -2028.97026 | 1500.03134 | 20.20092 |
| 22 | .00000 | 60.45020 | -162.42790 | 138.03408 | 73.99902 | -132.68622 | 38.04963 | -2028.97682 | 1500.01227 | 20.20172 |
| 23 | .00000 | 60.45020 | -162.42624 | 138.03301 | 73.99959 | -132.68558 | 38.04801 | -2028.98541 | 1499.99739 | 20.20148 |

CONSTANTS FOR SPHEROIDAL BUOY
DRAFT(FT)  A(FT)  DRAFT/A  VOL(CUFT)  VOL-Y(FT4)
5.3110    .5300  10.0000   3.1278    -5.3757

YCM-YCG= -1.7187 FT
EXACT SYI= 20.2015 DEG    APPX SYI= 24.2384 DEG

| FKS | FKH | FKP | FKPS | RUSO | CDAFC | CDASX |
|---|---|---|---|---|---|---|
| .9600 | .0558 | 20.1296 | -3.7271 | 56.5469 | .5013 | 3.1583 |

AVA= .0000    YVA= 4.7124

INITIAL VALUES AT TOP OF CABLE
XA= 6.6231   YA= 5.3310   AVA= .0000   YVA= 4.7124

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RUN NUMBER 1

STEADY-STATE CONFIGURATION

T(X)= 60.45   T(Y)= -162.43   DIRECTION= 1.00

| NODE | S REF(FT) | S STR(FT) | X(FT) | Y(FT) | TEN(LB) | PHIS(DEG) |
|------|-----------|-----------|-------|-------|---------|-----------|
| 0 | .00 | .00 | 6.82 | 5.31 | 173.31 | 20.41 |
|  | 100.00 | 100.78 | -35.30 | 46.77 | 169.75 | 28.70 |
|  | 200.00 | 201.54 | -88.74 | 182.13 | 166.45 | 35.12 |
|  | 200.00 | 201.54 | -88.74 | 182.13 | 166.45 | 35.12 |
|  | 550.00 | 554.11 | -327.04 | 440.10 | 156.55 | 48.87 |
|  | 900.00 | 906.53 | -609.13 | 651.97 | 148.37 | 56.72 |
|  | 900.00 | 906.53 | -609.13 | 651.97 | 174.57 | 45.93 |
|  | 1150.00 | 1359.98 | -953.98 | 946.00 | 163.03 | 52.81 |
|  | 1400.00 | 1813.21 | -1328.70 | 1200.57 | 152.97 | 48.88 |
|  | 1400.00 | 1813.21 | -1328.70 | 1200.57 | 148.17 | 62.22 |
|  | 2050.00 | 2087.03 | -1573.29 | 1323.63 | 145.98 | 64.37 |
|  | 2300.00 | 2360.14 | -1821.68 | 1437.14 | 143.96 | 66.62 |
|  | 2300.00 | 2360.14 | -1821.68 | 1437.14 | 139.14 | 72.27 |
|  | 2400.00 | 2468.52 | -1925.18 | 1469.36 | 138.57 | 73.14 |
|  | 2500.00 | 2576.83 | -2029.04 | 1500.00 | 138.03 | 74.00 |
|  | 2500.00 | 2576.83 | -2029.04 | 1500.00 | 138.03 | 74.00 |

X-COMPONENT OF TENSION= -142.69 LB
Y-COMPONENT OF TENSION= 38.05 LB

CABLE INITIAL CONDITIONS

| NODE | PHI(DEG) | TEN(LB) | X(FT) | Y(FT) | AV(FT/S) | AVI(FT/S) | YVI(FT/S) |
|------|----------|---------|-------|-------|----------|-----------|-----------|
| 1 | 28.6986 | 169.75 | -89.96 | 182.10 | .0000 | .0000 | .0000 |
| 2 | 48.8675 | 156.55 | -629.94 | 645.83 | .0000 | .0000 | .0000 |
| 3 | 52.8103 | 163.03 | -1343.23 | 1193.88 | .0000 | .0000 | .0000 |
| 4 | 64.3663 | 145.98 | -1836.31 | 1430.48 | .0000 | .0000 | .0000 |
| 5 | 73.1363 | 138.57 | -2043.68 | 1493.34 | .0000 | .0000 | .0000 |

TIME INFORMATION

INITIAL TIME INTERVAL= 10.0000 SEC   TIME STEP= .1000 SEC
TOTAL TIME= 50.0000 SEC   TIME STEP= .5000 SEC

COMPUTED CABLE SYSTEM MOTIONS AND TENSIONS

| NUM | T(SEC) | DT(SEC) | X(FT) | Y(FT) | XP(FT/S) | YP(FT/S) | XPP(I/SS) | YPP(FT/SS) | TEN(LB) | FT(DEG) | FTP(D/S) | STRAIN | SIP(I/S) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WAVE | .1000 | .000002 | 7.50 | -.22 | .1304 | 4.7104 | -2.9596 | .0857 | 5.86 | -.15 | 3.31 | | |
| BUOY | .1000 | .000002 | 7.49 | .34 | -.2075 | 3.7557 | -.5940 | -28.2901 DF= 148.32 | 24.11 | -4.15 SYPP= -71.05 D/SS | | |
| 0 | .1000 | .000002 | 6.81 | 5.64 | -.0917 | 1.7557 | | 19.0494 | 153.41 | 28.75 | .38 .006742 -.003593 | | |
| 1 | .1000 | .000002 | -90.03 | 182.17 | -1.6154 | 1.7313 | -17.2760 | 1.1328 | 161.00 | 48.87 | .02 .006973 -.003308 | | |
| 2 | .1000 | .000002 | -620.94 | 645.84 | -.0104 | .0575 | -1.0766 | .0492 | 145.98 | 52.81 | .00 .007404 -.000054 | | |
| 3 | .1000 | .000002 | -1343.23 | 1193.88 | .7070 | .0005 | .0132 | .0174 | 138.57 | 64.37 | .00 .093817 .000011 | | |
| 4 | .1000 | .006002 | -1836.31 | 1430.48 | .0015 | .0021 | | | | 73.14 | .00 .083451 .000004 | | |
| | | | MEAN DRAFT= | 5.50 | MEAN PITCH= | | 24.17 | PCT T DFTLIM= 65.49 | | PCT T SYDLIM= .00 | | |
| WAVE | .2000 | .012500 | 7.50 | .26 | -.1686 | 4.7096 | -2.9591 | -.1013 | 5.46 | .18 | 3.31 | | |
| BUOY | .2000 | .012500 | 7.46 | .41 | -.4054 | .1921 | -.42666 | -1.3513 DF= 171.97 | 23.44 | -7.50 SYPP= 26.28 D/SS | | |
| 0 | .2000 | .012500 | 6.80 | .71 | -1.1960 | .1921 | | | 144.81 | 28.78 | .19 .007817 .011498 | | |
| 1 | .2000 | .012500 | -90.23 | .38 | -1.8954 | 1.8823 | 13.2278 | -17.2719 | 162.53 | 48.87 | .01 .006582 -.003236 | | |
| 2 | .2000 | .012500 | -620.95 | 645.85 | -.2748 | .2942 | -4.0675 | 3.5124 | 145.98 | 52.81 | .00 .007388 -.000442 | | |
| 3 | .2000 | .012500 | -1343.23 | 1193.88 | .0034 | .0034 | -.1872 | .0411 | 138.57 | 64.37 | .00 .093818 .000001 | | |
| 4 | .2000 | .012500 | -1836.31 | 1430.48 | .0027 | .0035 | .0103 | .0119 | | 73.14 | .00 .083452 .000008 | | |
| | | | MEAN DRAFT= | 5.02 | MEAN PITCH= | | 23.97 | PCT T DFTLIM= 77.13 | | PCT T SYDLIM= .00 | | |
| WAVE | .3000 | .012500 | 7.46 | .73 | -.4606 | 4.6894 | -2.9467 | -.2894 | 5.03 | .51 | 3.29 | | |
| BUOY | .3000 | .012500 | 7.39 | .46 | -1.0183 | .9745 | -6.8027 | 12.2078 DF= 176.86 | 23.01 | .17 SYPP= 97.93 D/SS | | |
| 0 | .3000 | .012500 | 6.75 | 5.16 | -1.0232 | -.3556 | | | 143.12 | 28.78 | -.08 .008039 -.008383 | | |
| 1 | .3000 | .012500 | -90.33 | 182.46 | .0377 | .6560 | 16.7816 | -17.2617 | 160.91 | 48.87 | -.02 .006505 .001742 | | |
| 2 | .3000 | .012500 | -620.95 | 645.90 | .0475 | .0242 | -3.5352 | 3.0112 | 145.98 | 52.81 | .01 .007314 -.000999 | | |
| 3 | .3000 | .012500 | -1343.23 | 1193.88 | .0482 | .0035 | -.9323 | .3756 | 138.57 | 64.37 | -.00 .093814 -.000110 | | |
| 4 | .3000 | .012500 | -1836.31 | 1430.48 | .0036 | .0045 | .0076 | .0087 | | 73.14 | .00 .083453 .000011 | | |
| | | | MEAN DRAFT= | 5.02 | MEAN PITCH= | | 23.72 | PCT T DFTLIM= 51.42 | | PCT T SYDLIM= .00 | | |
| WAVE | .4000 | .012500 | 7.40 | 1.21 | -.7616 | 4.6504 | -2.9220 | -.4785 | 4.70 | .85 | 3.27 | | |
| BUOY | .4000 | .012500 | 7.26 | .61 | -1.5105 | 1.9141 | -2.3055 | 5.6738 DF= 147.02 | 23.39 | 5.60 SYPP= -9.12 D/SS | | |
| 0 | .4000 | .012500 | 6.61 | 5.91 | -1.6669 | 1.9141 | | 20.5081 | 148.75 | 28.77 | -.15 .006683 -.013623 | | |
| 1 | .4000 | .012500 | -90.49 | 182.40 | .0978 | -.2253 | -17.0067 | .0057 | 158.50 | 48.87 | -.01 .006761 .002018 | | |
| 2 | .4000 | .012500 | -621.09 | 645.98 | .8755 | .8079 | -.0617 | .8800 | 145.96 | 52.81 | .01 .007204 -.001090 | | |
| 3 | .4000 | .012520 | -1343.24 | 1193.88 | -.1926 | .0045 | -1.9469 | .0099 | 138.57 | 64.37 | -.00 .093789 -.000423 | | |
| 4 | .4000 | .012500 | -1836.31 | 1430.48 | .0040 | .0054 | -.0009 | | | 73.14 | .00 .083454 .000011 | | |
| | | | MEAN DRAFT= | 5.34 | MEAN PITCH= | | 23.59 | PCT T DFTLIM= 38.56 | | PCT T SYDLIM= .00 | | |
| WAVE | .5000 | .006250 | 7.31 | 1.69 | -1.0604 | 4.5914 | -2.8849 | -.6665 | 4.44 | 1.19 | 3.23 | | |
| BUOY | .5000 | .006250 | 7.11 | .83 | -1.5073 | 2.4659 | 1.5163 | 8.3990 DF= 134.01 | 23.70 | -1.19 SYPP= -106.10 D/SS | | |
| 0 | .5000 | .006250 | 6.44 | 6.11 | -1.4740 | 2.4659 | | 25.6776 | 147.55 | 28.77 | -.20 .006091 .002472 | | |
| 1 | .5000 | .006250 | -90.40 | 182.51 | -2.3352 | 2.5570 | -22.8017 | -.1411 | 156.46 | 48.87 | .03 .006707 -.003305 | | |
| 2 | .5000 | .006250 | -621.26 | 646.06 | -.8256 | .7686 | .8027 | 1.2500 | 145.91 | 52.81 | .01 .007112 -.000742 | | |
| 3 | .5000 | .006250 | -1343.27 | 1193.90 | -.4257 | .1902 | -2.6284 | .0183 | 138.57 | 64.37 | -.00 .093723 -.000932 | | |
| 4 | .5000 | .006250 | -1836.31 | 1430.48 | .0031 | .0068 | -.0202 | | | 73.14 | .00 .083455 .000005 | | |
| | | | MEAN DRAFT= | 5.18 | MEAN PITCH= | | 23.59 | PCT T DFTLIM= 30.85 | | PCT T SYDLIM= .00 | | |
| WAVE | .6000 | .006250 | 7.18 | 2.16 | -1.3550 | 4.5134 | -2.8358 | -.8513 | 4.28 | 1.51 | 3.17 | | |
| BUOY | .6000 | .006250 | 6.96 | 1.14 | -1.4050 | 3.9127 | -.1047 | 19.8791 DF= 146.23 | 23.07 | -10.63 SYPP= -65.36 D/SS | | |
| 0 | .6000 | .006250 | 6.32 | 6.44 | -1.1081 | 3.9127 | | | 137.03 | 28.88 | .59 .006647 .304402 | | |
| 1 | .6000 | .006250 | -90.71 | 182.84 | -3.3633 | 3.6771 | 2.1684 | -3.1826 | 155.06 | 48.87 | .04 .006229 -.005201 | | |
| 2 | .6000 | .006250 | -621.26 | 646.14 | -.9628 | .8914 | -3.1441 | 2.7356 | 145.82 | 52.81 | .02 .007048 -.000607 | | |
| 3 | .6000 | .006250 | -1343.33 | 1193.92 | -.7038 | .3293 | -2.8901 | 1.5143 | 138.57 | 64.37 | -.00 .093600 -.001545 | | |
| 4 | .6000 | .006250 | -1836.31 | 1430.48 | -.0005 | .0094 | -.0036 | .0357 | | 73.14 | .00 .083454 .000016 | | |
| | | | MEAN DRAFT= | 5.04 | MEAN PITCH= | | 23.55 | PCT T DFTLIM= 25.71 | | PCT T SYDLIM= .00 | | |
| WAVE | .7000 | .012500 | 7.03 | 2.62 | -1.6435 | 4.4165 | -2.7750 | -1.0327 | 4.31 | 1.84 | 3.10 | | |
| BUOY | .7000 | .012500 | 6.82 | 1.63 | -1.5142 | 5.8819 | -1.4715 | 14.3957 DF= 141.45 | 21.79 | -14.18 SYPP= -18.92 D/SS | | |
| 0 | .7000 | .012500 | 6.21 | 6.91 | -1.1162 | 5.8119 | | -4.7026 | 127.84 | 28.88 | .79 .006410 -.008678 | | |
| 1 | .7000 | .012500 | -91.01 | 183.18 | -2.7157 | 2.9486 | 5.3161 | 4.5101 | 153.47 | 52.82 | .03 .005813 -.002982 | | |
| 2 | .7000 | .012500 | -621.37 | 646.24 | -1.4064 | 1.2740 | -5.2495 | | | | .02 .006976 -.000880 | | |

# REFERENCES

1.  "Analysis Of The Two Dimensional Steady State Behavior Of Extensible Free-Floating Cable Systems," Henry T. Wang and Thomas L. Moran, NSRDC Report 3721, Oct 1971

2.  "Effect Of Nonplanar Current Profiles On The Configuration Of Moored Cable Systems," Henry T. Wang, NSRDC Report 3692, Oct 1971

3.  "A Fortran IV Computer Program For The Time Domain Analysis Of The Two Dimensional Dynamic Motions of General Buoy-Cable-Body Systems," Henry T. Wang, NSRDC Report 77-0046, Jun 1977

4.  "Computer Generated Random Sea Surfaces For Use With The Program CARBUOY," John Brett, NADC-77271-20, 30 Sep 1977

## APPENDIX A

### DEFINITION OF INPUT VARIABLES

| | | |
|---|---|---|
| NCASES | — | Number of cases to be run. One case is defined by data cards 2 through 17. NCASES $\geq$ 1 |
| TITLE | — | Title of data case. Title is printed on output for identification. |
| NSM | — | Number of surface motion components. For 1000 $\leq$ FMS (1) < 2000 Surface motion = Surface Wave, NSM is automatically set equal to NSW. 1 $\leq$ NSM $\leq$ 20 |
| NSW | — | Number of surface wave components. 1 $\leq$ NSW $\leq$ 20 |
| NCAB | — | Number of cable segments. 2 $\leq$ NCAB $\leq$ 50 |
| NCUR | — | Number of current profile data points. 2 $\leq$ NCUR $\leq$ 10 |
| ITER | — ITER | = 0   prescribed initial steady state conditions |
| | | = 1   free floating cable system |
| | | = 2   moored cable with given length in given depth |
| | | = 3   towed cable system |
| | | = 4   iteration scheme to be programmed by user |
| MTRC | — MTRC | $\leq$ 0 if input data are entered in English units. $\geq$ 1 if input data are entered in metric units. |
| IBUOY | — IBUOY | < - 10 Surface buoy drag areas and added masses remain at constant values, and displaced volume is equal to the draft times the steady-state waterplane area. |
| | | < - 1   Surface buoy drag areas and added masses remain at constant values corresponding to the steady-stae draft. |
| | | = 0   Surface buoy drag areas and added masses are updated at the end of each print interval. |
| | | < 1   Surface buoy drag areas and added masses are updated continuously as a function of buoy submergence. |
| ISPAR | | Degree of polynomial used to approximate variation of cross sectional area of a spar buoy. ISPAR $\leq$ NSM-1 |

AXSM
AYSM
FSM
FIDSM
} FSM (1) $\leq$ 1000 Amplitude, frequency and phase of surface motion which is defined by the equations:

$$X_{sm} = \sum_{k=1}^{NSM} AXSM\,(k) * COS\,(-2\pi * FSM\,(k) * t + FIDSM\,(k) * \pi/180)$$

$$Y_{sm} = \sum_{k=1}^{NSM} -AYSM\,(K) * SIN\,(-2\pi * FSM\,(k) * t + FIDSM\,(k) * \pi/180)$$

(ft., hz & deg or m, hz & deg)

1000 $\leq$ FSM (1) < 2000 = Prescribed surface motion components are set equal to the surface wave components by setting AXSM (k) = AYSM (k) = ASW (k), FSM (k) = FRSW (k), FIDSM (k) = FIDSW (k) and NSM = NSW.

2000 $\leq$ FSM (1) < 2900 - Surface buoy is considered to be a spar buoy. Program calculates the inertia and forcing coefficients. AXSM (k) is the cross-sectional area of the buoy at a vertical distance AYSM (k) from the origin of

## APPENDIX A (Cont'd)

the local buoy coordinate system. AYSM (NSM)-AYSM (1) is the total length of the buoy. FIDSM (1) is the added mass coefficient for surge, Ks. FIDSM (2) is the ratio $\sigma = $ Isw/ $(\pi r_w^4/4)$, where Isw is the moment of inertia of the water plan area and $r_w$ is the radius of the water plane cross section. For a circular section spar buoy, $K_s = \sigma = 1$. These values are automatically preset if FIDSM (1) = FIDSM (1) = 0. All inertia and forcing coefficients are calculated by the program.

$2900 \leq$ FSM (1) $< 3000$  Surface buoy is considered to be an arbitrary shape. Inertia and forcing coefficients are input as data. AXSM (k), AYSM (k), FSM (k) and FIDSM (k) are defined as for a spar buoy.

$3000 \leq$ FSM $< 4000$  Surface buoy is considered to be a spheroid. AXSM (1) and AYSM (1) are the horizontal and vertical semi-axes. All other variables should be set equal to 0.

ASW ⎫
FRSW ⎬    ASW $< 1000$, amplitude, frequency and phase of surface wave components, which
FIDSW ⎭    are defined by the equation:

$$X_{sw} = \sum_{k=1}^{NSW} ASW\,(k) * COS\,(-2\pi * FRSW\,(k) * t + FIDSW\,(k) * \pi/180).$$

$$Y_{sw} = \sum_{k=1}^{NSW} -ASW\,(k) * SIN\,(-2\pi * FRSW\,(k) * t + FIDSW\,(k) * \pi/180).$$

(ft, Hz & deg or m, Hz & deg).

$1000 \leq$ ASW (1) $< 2000$ sea surface is generated using the Pierson-Moskowitz sea spectrum. ASW (1) -1000 is the significant wave height, and FRSW (1) and FRSW (2) are the lower and upper frequencies of the spectrum. Wave components are phase shifted by 360/NSW degrees, with FIDSW (1) being the phase of the lowest frequency component.

$2003 \leq$ ASW (1) $\leq 2008$  A standardized random sea surface is generated using internally generated wave components.
ASW (1) -2000. is the desired sea state. Sea states 3 through 8 are available.

| | |
|---|---|
| RHO | Fluid density ($^{slugs}$/ft$^3$ or $^{kg}$/m$^3$) |
| AMC | Added mass coefficient for cable. AMC = 1.0 for round cable |
| AFAC | Cross-sectional correction factor. AFAC = 1.0 for cylindrical cable. AFAC = cable cross-sectional area / $(\pi d^2/4)$ for non-round cable. |
| TBH | Applied force on lower weight in x- direction (lbs or N) |
| TBYMX | Maximum absolute value of tension in cable just below buoy. For buoy-cable systems, set TBYMX = 99999. (lbs or N) |
| SUBM | Depth at which current velocity is measured for surface float drag calculations (ft. or m). |
| TWX | Horizontal force acting at the top of the cable (lb or N). For cases with a float, TWX represents the wind loading. |
| TIY | Vertical component of tension at top of cable (lb or N). |

## APPENDIX A (Cont'd)

For cases with a float, $TIY = -$(steady-state buoyancy of float).

|  |  |
|---|---|
| TMIN | Minimum tension which can be supported by cable, (lb or N). |
| CDASPX | Drag area of surface package in x direction (ft$^2$ or M$^2$). |
| CDASBX | Drag area of surface buoy, excluding surface package, in x direction (ft$^2$ or M$^2$). |
| VSP | Volume of surface package (ft$^3$ or M$^3$). |
| SPXK | Surface package added mass coefficient for surge. |
| SPYK | Surface package added mass coefficient for heave. |
| YYSP | Vertical distance of center of buoyancy of surface package measured from the origin of the local buoy coordinates (ft or M). |
| TINV1 | Initial print time interval (sec). |
| DT1 | Print time step during initial interval (sec). |
| TOTT | Total time for which dynamic calculations are desired (sec). |
| DT2 | Print time step during final interval (sec). |
| FLC | Length of cable segment (ft or m). |
| DCI | Diameter of cable segment (in. or cm). |
| CDN | Normal drag coefficient of cable segment. |
| CDT | Tangential drag coefficient of cable segment. |
| WC | Weight in fluid of the cable segment at the reference cable tension ($^{lbs}$/ft or $^n$/m). |
| CM | Mass of cable segment at the reference cable tension (slugs/ft or kg/m). |
| C1 | The stress-strain curve for the segment is defined by the |
| C2 | equation |
| CINT | Tension $= TREF + C1 \cdot \varepsilon^{C2} + CINT \cdot \dot{\varepsilon}$ |
| TREF | For linearly elastic materials, $C1 = AE$ and $C2 = 1$. |
| | For free floating and towed cases (ITER $= 1$ or 3) the last cable segment connecting the lower weight to the ocean bottom is fictitious. In these cases, $C1 = DCI = CDN = CDT = WC = CM = CINT = 0$, $FLC = 2 \cdot FLC$ (NCAB - 1) and $C2 = 1$. These values are set automatically. Blank cards should be inserted for data. |
| TENI | PHID $< 360$ TENI is the initial value of cable tension (lbs or N). |
| PHID | PHID is initial value of cable tilt ($\Phi$) (deg). |
| | PHID $\geq 360$ Initial values of tension and cable tilt are set equal to steady-state values calculated by the program. In this case, 0 can be entered for TENI. |
| XPI | Initial value of $\dot{x}$ (ft/sec or $^m$/sec). |
| YPI | Initial value of $\dot{y}$ (ft/sec or $^m$/sec). |
| WBD | Weight in fluid of body (lb or N). |
| CDABX | Drag area of body in x direction (ft$^2$ or m$^2$). |
| CDABY | Drag area of body in y direction (ft$^2$ or m$^2$). |
| XMBV | Virtual mass of body in x direction (slugs or kg). |
| YMBV | Virtual mass of body in Y direction (slugs or kg). |
| | If CDABX is negative, the program considers the body to be a circular disk with plane perpendicular to the x-axis, and calculates the drag and added mass, using $|CDABX|$ as the actual drag area and XMBV as the actual mass of the disk. CDABY and YMBV retain their original definitions. Similar remarks apply if CDABY is negative, except that the plane of the disk is now perpendicular to the Y axis. |

## APPENDIX A (Cont'd)

| | |
|---|---|
| YY | Depth of current velocity data point (ft or m). For moored case, YY (NCUR) is the ocean bottom. |
| CCK | Velocity of current at depth YY (kts or m/sec). |
| CDASY | Drag area of surface buoy in Y direction ($ft^2$ or $m^2$). |
| WAST | Weight in air of buoy and surface package (lb or N). |
| RWY | Vertical distance of wind loading center of pressure from buoy center of gravity (YCG) (ft or m). |
| RTX | Distance of cable attachment point from YCG in x direction (ft or m). |
| RTY | Distance of cable attachment point from YCG in y direction (ft or m). |
| YCG | Vertical distance of center of gravity of buoy and surface package measured from the origin of the local buoy coordinate system (ft or m). |
| BINT | Moment of inertia of buoy and surface package about YCG (slug $ft^2$ or $km^2$). |
| XSI | Initial values of $x, \zeta, \psi$), where $\zeta$ is the vertical displacement of the float center |
| ZETI | of gravity from its equilibrium position (ft, ft & deg or m, m & deg). |
| SYDI | For SYDI $\geq$ 360, the program sets the initial values for buoy inclination, draft and vertical velocity equal to the steady-state values previously calculated by the program. This will minimize transient dynamic motions of the surface body. |
| XPSI | Initial values of $(\dot{x}, \dot{\zeta}, \dot{\psi})$, (ft/sec, ft/sec, Deg/sec or m/sec, m/sec, deg/sec). |
| ZTPI | |
| SYPDI | |
| DFTLIM | Limiting value of draft and pitch for which the program calculates the percent of |
| SYDLIM | time these values are exceeded. |

(The following variables are described in NSRDC/SPD-0633-02)

| | |
|---|---|
| AKZ | Added mass coefficient in heave for arbitrary buoy. |
| AXP | $A_{\xi\psi}/\rho VL$ for arbitrary buoy |
| APP | $(A_{\psi\psi} - BINT)/\rho VL^2$ for arbitrary buoy |
| AFKX | $FKx/\rho V \ddot{x}_\omega$ for arbitary buoy |
| AFKZ | $FKy/\rho V \ddot{y}_\omega$ for arbitrary buoy |
| AFKP | $FK_\psi/\rho VL \dot{x}_\omega$ |

## APPENDIX B

## CABUOY
## INPUT PARAMETERS
## DATA FORMAT GUIDE

| Card | Col | FMT | Variable |
|------|------|--------|----------|
| 1 | 1-3 | I3 | NCASES |
| 2 | 1-80 | 20A4 | TITLE |
| 3 | 1-3 | I3 | NSM |
| | 4-6 | I3 | NSW |
| | 7-9 | I3 | NCAB |
| | 10-12 | I3 | NCUR |
| | 13-15 | I3 | ITER |
| | 16-18 | I3 | MTRC |
| | 19-21 | I3 | IBUOY |
| | 22-24 | I3 | ISPAR |
| 4 | 1-10 | F10.4 | AXSM (I) |
| | 11-20 | F10.4 | AYSM (I) |
| | 21-30 | F10.4 | FSM (I) |
| | 31-40 | F10.4 | FIDSM (I) |
| 5 | 1-10 | F10.4 | ASW (J) |
| | 11-20 | F10.4 | FRSW (J) |
| | 21-30 | F10.4 | FIDSW (J) |
| 6 | 1-10 | F10.4 | RHO |
| | 11-20 | F10.4 | AMC |
| | 21-30 | F10.4 | AFAC |
| | 31-40 | F10.4 | TBH |
| | 41-50 | F10.4 | TBYMX |
| 7 | 1-10 | F10.4 | SUBM |
| | 11-20 | F10.4 | TWX |
| | 21-30 | F10.4 | TIY |
| | 31-40 | F10.4 | TMIN |
| 8 | 1-10 | F10.4 | CDASPX |
| | 11-20 | F10.4 | CDASBX |
| | 21-30 | F10.4 | VSP |
| | 31-40 | F10.4 | SPXK |
| | 41-50 | F10.4 | SPYK |
| | 51-60 | F10.4 | YYSP |
| 9 | 1-10 | F10.4 | TINVI |
| | 11-20 | F10.4 | DT1 |
| | 21-30 | F10.4 | TOTT |
| | 31-40 | F10.4 | DT2 |
| 10 | 1-10 | F10.2 | FLC (K) |
| | 11-20 | F10.4 | DCI (K) |
| | 21-30 | F10.4 | CDN (K) |
| | 31-40 | F10.4 | CDT (K) |
| | 41-50 | F10.4 | WC (K) |
| | 51-60 | F10.6 | CM (K) |

**APPENDIX B** (Cont'd)

**CABUOY**

**INPUT PARAMETERS**

**DATA FORMAT GUIDE**

| | | | |
|---|---|---|---|
| 11 | 1-10 | F10.0 | C1 (K) |
| | 11-20 | F10.4 | C2 (K) |
| | 21-30 | F10.4 | CINT (K) |
| | 31-40 | F10.2 | TREF (K) |
| | 41-50 | F10.2 | TENI (K) |
| | 51-60 | F10.4 | PHID (K) |
| | 61-70 | F10.4 | XPI (K) |
| | 71-80 | F10.4 | YPI (K) |
| 12 | 1-10 | F10.4 | WBD (K) |
| | 11-20 | F10.4 | CDABX (K) |
| | 21-30 | F10.4 | CDABY (K) |
| | 31-40 | F10.4 | XMBV (K) |
| | 41-50 | F10.4 | YMBV (K) |
| 13 | 1-10,.... | F10.4 | YY (L) |
| 14 | 1-10,.... | F10.4 | CCK (L) |
| 15 | 1-10 | F10.4 | CDASY |
| | 11-20 | F10.4 | WAST |
| | 21-30 | F10.4 | RWY |
| | 31-40 | F10.4 | RTX |
| | 41-50 | F10.4 | RTY |
| | 51-60 | F10.4 | YCG |
| | 61-70 | F10.4 | BINT |
| 16 | 1-10 | F10.4 | XSI |
| | 11-20 | F10.4 | ZETI |
| | 21-30 | F10.4 | SYDI |
| | 31-40 | F10.4 | XPSI |
| | 41-50 | F10.4 | ZTPI |
| | 51-60 | F10.4 | SYPDI |
| | 61-70 | F10.4 | DFTLIM |
| | 71-80 | F10.4 | SYDLIM |

This card is only needed if 2900< FSM (1) < 3000

| | | | |
|---|---|---|---|
| 17 | 1-10 | F10.4 | AKZ |
| | 11-20 | F10.4 | AXP |
| | 21-30 | F10.4 | APP |
| | 31-40 | F10.4 | AFKX |
| | 41-50 | F10.4 | AFKZ |
| | 51-60 | F10.4 | AFKP |

## APPENDIX C

## CABUOY OUTPUT VARIABLES

### Ocean Conditions

#### Surface Wave

FREQ — Frequency of wave component (hz)
AMPL — Amplitude of wave component (feet)
PHASE — Phase of wave component (degrees)
WL — Wave length of component (feet)
WK — Wave number of component (1/feet)

### Current Profile

DEPTH — Depth of current data point (feet)
CURR — Current velocity at depth (DEPTH) (knots)

### Surface Motion

#### FREQ < 1000

FREQ — Frequency of surface motion component (hz)
X-A — X amplitude of motion component (ft)
Y-A — Y amplitude of motion component (ft)
PHASE — Phase shift of motion component (both X&Y) (degrees)

#### 2000 < FREQ < 3000

FREQ — Input numbers for FSM - Spar buoy
X-A — Cross sectional area at distance Y-A (ft $^2$) from origin
Y-A — Position of cross sectional area data point relative to origin (ft).
PHASE — 0

#### 3000< FREQ

FREQ — Input data for FSM (Spheroid)
X-A — Radius of float at waterline (ft) in X-Z plane.
Y-A — Radius of float at waterline (ft) in Y-Z plane.
PHASE — 0

### General Cable Characteristics

AM COEFF — Cable Added Mass Coefficient (AMC)
AREA FAC — Cross Sectional Area Correction Factor (AFAC)
T MIN — Minimum tension cable can support (lbs)

## APPENDIX C (Cont'd)

### Cable Properties

NUM — Cable Segment Number
LEN — Length of segment at reference tension (ft)
DIAM — Diameter of segment (in.)

CDN — Coefficient of drag normal to cable
CDT — Coefficient of drag tangent to cable
W — Wet weight of cable (lbs/ft)
M — Mass of cable (slugs/ft)
T — Reference tension of cable (lbs)
CI, EXPC2 Coefficients for stress strain equation $T = c1\epsilon^{C2}$
CINT — Internal damping coefficient

### Body Properties

CDAY — Drag area in X-Z plane ($ft^2$)
CDAX — Drag area in Y-Z plane ($ft^2$)
WT — Wet weight of body (lbs)
XVM — Virtual mass in X direction (slugs)
YVM — Virtual mass in Y direction (slugs)
X-Load on BOT-WT = Applied force on lower weight (lbs) (TBH)

### Surface Buoy Characteristics

WIND LD — Wind loading on surface float (lbs) (TWX)
SUBM — Depth at which current acts on surface float (ft)
CDASPX — Drag area of subsurface package in x direction ($ft^2$)
CDASBX — Drag area of surface float excluding subsurface package in x direction ($ft^2$)
AVSPX ⎱
AVSPY ⎰ Virtual mass of surface package in x and y directions ($ft^3$)
MAXTEN — Maximum tension which can be supported by the cable (lbs)
BUOY CALC — variable IBUOY
SPAR NUM — Degree of polynomial of spar flat (ISPAR)
CDAY — Drag area in X-Z plane ($ft^2$)
WT — Weight in air of float (lbs)
RWY — Vertical distance of wind loading from cg (ft)
RTX — Distance in x direction of cable attachment point from $c_g$ (ft)
RTY — Distance in Y direction of cable attachment point from $c_g$ (ft)
YCG — Submergence of cg below waterline (ft)
IN — Moment of inertia of surface float (slugs ft squared)
XI
ZETA ⎱
SYI ⎰ — Initial values of $x, \zeta, \Phi$ for surface float in feet, feet, degrees
XVI ⎱
ZTVI � Initial velocities of $x, \zeta, \Phi$ for surface float in feet/sec, feet/sec., degr s/sec
SYVI ⎰

## APPENDIX C (Cont'd)

### Constants for Spar Buoy

Initial Ratio TY = total tension at top of cable plus weight of surface float

$$PO = \rho \ast \text{ Surface float displaced volume}$$

$$P1 = \rho \int_o^h (y - y_{cg}) \, S y \, dy$$

$$P2 = \rho \int_o^h (y - y_{cg})^2 \, S y \, dy$$

$$Q0 = \rho \int_o^h (y - y_{cg}) \, e^{-ky} \, S y \, dy$$

$$Q1 = \rho \int_o^h (y - y_{cg})^2 e^{-ky} \, S y \, dy$$

| | |
|---|---|
| WVMZ | — Virtual mass of body in heave |
| RGSO | — $\rho \ast g \ast$ cross sectional area at the surface |
| YCB-YCG | — Separation of center of buoyancy and center of gravity |
| EXACT SYI | — Steady state pitch angle of float in degrees |
| APPR SYI | — Value of float pitch used in dynamic calculations. May vary from exact SYI because of cable segment approximations made in CABUOY |

### Constants for Spheroidal Buoy

| | |
|---|---|
| DRAFT | — Draft of surface float (ft) |
| A | — Cross sectional area at the waterline (ft$^2$) |
| VOL | — Displaced volume of float (ft $^3$) |
| FKS | — Added mass coefficient in surge |
| FKH | — Added mass coefficient in heave |
| FKP | — Added mass coefficient in pitch |
| FKPS | — Coefficient of coupling between pitch and surge |
| RGSO | — Water density $\ast$ acceleration due to gravity $\ast$ surface float cross-sectional area at the waterline |
| CDAFC | — Drag coefficient for submerged portion of the float in X direction |
| CDASX | — Submerged drag area of surface assembly |
| EXACT SYI | — Surface float tilt (see spar buoy) |
| APPR SYI | — Approximate float tilt for dynamic calculations |

### Iteration

| | |
|---|---|
| ITN | — Iteration number |
| VCXK | — System drift velocity (knots) |
| TIXX | — X Component of tension at top of cable (lbs) |
| TIYY | — Y Component of tension at top of cable (lbs) |
| TENB | — Tension at bottom weight (lbs) |
| PHIB | — Inclination of cable at bottom relative to vertical (degrees) |
| TBXX | — X Component of tension at bottom (lbs) |
| TBYY | — Y Component of tension at bottom (lbs) |

**APPENDIX C** (Cont'd)

| | |
|---|---|
| XXBB | — X Coordinate at bottom of cable (ft) |
| YYBB | — Y Coordinate at bottom of cable (ft) |
| SYSS | — Pitch of surface float (degrees) |

**Steady State Configuration**

| | |
|---|---|
| TIX | — Tension at top of cable in X direction (lbs) |
| TIY | — Tension at top of cable in Y direction (lbs) |
| DIRECTION | — Initial conditions known at top or bottom (DIR) |
| NODE | — End point of cable segment |
| S REF | — Distance along reference length of cable (ft) |
| S STR | — Stretched length of cable (ft) |
| X | — X position of NODE (ft) |
| Y | — Y position of NODE (ft) |
| TEN | — Tension in cable at NODE (lbs) |
| PHIS | — Tilt of cable reference to vertical (degrees) |

**Cable Initial Conditions**

| | |
|---|---|
| PHI | — Tilt of cable at NODE (degrees) |
| XV | — X Velocity of NODE (ft/sec) |
| YV | — Y Velocity of NODE (ft/sec) |

**Computer Cable System Motions**

| | |
|---|---|
| T | — Current time of dynamic data (sec) |
| DT | — Integration time step (sec) |
| X | — X Position of body (ft) |
| Y | — Y Position of body (ft) |
| XP | — X Velocity of NODE (ft/sec) |
| YP | — Y Velocity of NODE (ft/sec) |
| XPP | — X Acceleration of NODE (ft/sec$^2$) |
| YPP | — Y Acceleration of NODE (ft/sec$^2$) |
| TEN | — Cable Tension (lbs) |
| FI | — Angle of cable at NODE (degrees) |
| FIP | — Rate of change of angle (deg/sec) |
| STRAIN | — Cable strain |
| STP | — Rate of cable strain (1/sec) |
| SYPP | — Angular acceleration of float pitch (eg/sec$^2$) |
| DF | — Surface float draft (ft) |
| PCT T DFTLIM ⎫ | — Percent of time float exceeds draft and |
| PCT T SYDLIM ⎭ | Tilt limits |
| WAVE | — Data for surface wave |
| BUOY | — Data for origin of surface float |
| 0 | — Data for top of cable segment number 1 |
| 1 | — Data for bottom of cable segment number 1 |
| 2 | — Data for bottom of cable segment number 2 |

Note: Data for bottom of last cable segment is not printed out as point is assumed to be fixed in space

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